Science Visions, Science Fiction and the Roots of Computational Intelligence

Rudolf Seising

Abstract. In later science fiction movies, computers run countries or govern the whole mankind but in science fiction stories of the 1950s this scenario does not exist. It seems that it originated from the early Computer Science and it was Lotfi A. Zadeh who published in 1950 the first science vision of a "Thinking Machine". He also predicted in 1950 that "Thinking machines" may be commonplace in anywhere from ten to twenty years hence and that they will play a major role in any armed conflict. Not many years later new SF stories told these kinds of stories of computers that govern the world by their decision — sometimes they annihilate the earth, sometimes they protect the planet. This paper gives a historical view on the idea of "machines that/who thinks" in science visions and in science fiction. Then, it shows this idea's historical path from the research program of Artificial Intelligence to that of Computational Intelligence.

1 Introduction

Is there a difference between "Machines that compute" and "Machines that think"? — We are tempted to say that the answer is obviously "Yes!" and perhaps many of us could start to list some distinctive features immediately. However, this is a result from 20th century science and technology and its reflections in science and science fiction literature. Both will be traced in this chapter.

There was a time when both "Computing Machines" and "Thinking Machines" have been names for the same! — The buzz word "Thinking Machine" appeared in popular journals and newspapers, in science fiction stories, but also in scientific articles: Shortly after the end of World War II the general public became informed on the war development of computer and communication technology and a big number of headlines said that these new created machines were "mechanical"

Rudolf Seising
European Centre for Soft Computing, Edificio de Investigación, 33600 Mieres (Asturias), Spain
e-mail: rudolf.seising@softcomputing.es

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(*The Baltimore Sun*) or “electronical” (*New York Herald Tribune*) or “mathematical brains” (*Philadelphia Inquire*), but they were also named “wonder brains” (*Philadelphia Inquire*), “magic brains” (*New York World Telegram*) and “super-brains” (*Newark Star Ledger*). They notified that these apparatus had a weight of 30 tons (*The Evening Bulletin, Providence*), they were 1000 times faster than any previously built (*Chicago Sun*) and they could compute a 100-year problem in two hours (*New York Herald Tribune*) ([22], p. 120.).

The first book that continued this trend was *Giant Brains or Machines that Think*. It was published by the mathematician Edmund C. Berkeley (1923–1988) in 1949. In this book Berkeley gave a description of the functionality of the early computing machines — the book cover promoted that “an authority tells the story of ‘mechanical brains’ — how they ‘think’, what they do and what they can mean in your future.”[5]

“Can machines think?” was also the question that interested the British mathematician Alan M. Turing (1912-1954) in his article “Computing Machinery and Intelligence” that appeared one year later [47]. However, Turing started as follows: “I propose to consider the question, ‘Can machines think?”’ But: Since “thinking” is difficult to define, he chose to “replace the question by another, which is closely related to it and is expressed in relatively unambiguous words.” ([47], p. 433) Now, Turing considered the question “Are there imaginable digital computers which would do well in the imitation game?” ([47], p. 442) that — as he believed — was one that could actually be answered and to this end he proposed the “imitation game” that was later named the “Turing test”. Thus, there was no statement in Turing’s paper to decide whether a computer or a program could think like a human being or not.

Being unaware of Turing’s article, but inspired by Norbert Wiener’s (1894–1964) *Cybernetics* [48], Claude E. Shannon’s (1916–2001) “Mathematical Theory of Communication” [44] and the computer era that started during the wartime with the *Electronic Numerical Integrator and Computer* (ENIAC) and the *Electronic Discrete Variable Computer* (EDVAC) (both designed by John P. Eckert (1919-1995) and John W. Mauchly (1907–1980)), Lotfi A. Zadeh wrote in the same year the article “Thinking Machines: A New Field in Electrical Engineering.”

Zadeh, born 1921 in Baku, Azerbaijan, had studied and graduated with a Bachelor of Science in electrical engineering from the University of Tehran, Iran, in 1942. After working as a technical contractor for a year with the US army forces in Iran he had moved to the USA in 1944. There, he continued his studies at MIT where he received an M.S. degree in 1946. In 1949 he had obtained a position at Columbia University in New York as an instructor responsible for teaching the theories of circuits and electromagnetism.

Then, also in that year, he had the opportunity to organize and moderate a debate meeting about digital computers in which Shannon, Berkeley and Francis J. Murray (1911-1996) took part. It was probably the first public debate on this subject ever! [42]

Due to this deep interest he turned his attention to the problems of computers when he had received his Ph.D., and in 1950, when he became an assistant professor, he published the paper on "Thinking Machines" in *The Columbia Engineering Quarterly*, an electrical engieneering students' journal [49]. He also featured such headlines:

> "'Psychologists Report Memory is Electrical', 'Electric Brain Able to Translate Foreign Languages is Being Built', 'Electronic Brain Does Research', 'Scientists Confer on electronic Brain' — these are some of the headlines that were carried in newspapers throughout the nation during the past year. What is behind the headlines? How will 'electronic brains' or 'Thinking Machines' affect our way of living? What is the role played by electrical engineers in the design of these devices? These are some of the questions that we shall try to answer in this article." ([49], p. 12.)

You would think that possible answers to these questions were given in science fiction stories that have been written very soon after World War II but it is not as simple as that! One of the most famous writers of such stories was Isaac Asimov (1919–1992) who started writing sold SF stories — of course without any computers contained — for the *Amazing Stories* magazine in the late 1930s.

In the 1940s Asimov wrote many of his robot stories and some of them, e.g. "The Bicentennial Man", were made into later films. Also other contents of Asimov's robot stories have been incorporated in the settings of SF movies in the last three decades, e.g. "Little Lost Robot" that was first published in the March 1947 issue of *Astounding Science Fiction* and "I, Robot" that was originally a SF short story by Eando Binder[1], already published in the January 1939 issue of *Amazing Stories*. This story influenced Asimov to write nine robot stories in the collection *I, Robot* [1].[2]

SF action movies of the 1990s until today, e.g. *Matrix* and *Terminator*, show scenarios of the world where computers run countries or govern the whole mankind. In *The Terminator*,[3] that plays in the year 2029 after an apocalypse, artificially intelligent machines intend to exterminate all human beings. The American SF action film series of *The Matrix*[4] describes the fight of a small group of humans against artificial intelligent machines that dominate the Earth of the 21st century. These machines control the minds of all other humans by implants connecting them to a simulated reality called "The Matrix".

It is important to notice that these dystopic scenarios of a world, that is dominated by computers, were not in the settings of that early science fiction stories. On the

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[1] Under the Eando name, the brothers Earl Andrew Binder (1904–1965) and Otto Binder (1911–1974) ("E" and "O Binder") wrote science fiction stories on a robot named Adam Link.

[2] These stories originally appeared in the American magazines *Super Science Stories* and *Astounding Science Fiction* between 1940 and 1950. Asimov had titled this collection *Mind and Iron* but the publisher changed the title without his approval.

[3] *The Terminator*, 1984, *Terminator 2: Judgment Day*, 1991, and *Terminator 3: Rise of the Machines*, 2003, American science fiction action films; Director: James Cameron, Co-writers: James Cameron, William Wisher Jr., and *Terminator Salvation*, 2009 Director: Joseph McGinty Nichol, Co-writers: John Brancato and Michael Ferris.

[4] *The Matrix*, 1999, *The Matrix Reloaded*, 2003, and *The Matrix Revolutions*, 2003; Directors and Writers: Larry and Andy Wachowski.

contrary, a large number of them have been "Computer-is-God stories" wrote author John Clute in 1995 in his *Illustrated Encyclopedia* on science fiction:

Later the "Computer-is-God stories" turned into "Computer-can-think stories". An example is the movie *Wargames*[5], a Cold War story on computer-controlled nuclear disarmament. The movie begins with a simulated nuclear attack to the USA by the Soviet Union. It turns out that 22% of the US Air Force Strategic Missile Wing missileers prove unwilling to turn a key required to launch a missile strike. Therefore the command of missile silos is maintained through automation, without human intervention. Control is given to the NORAD[6] computer, WOPR (War Operation Plan Response), a learning expert system.

A high school student hacks this computer by accident when he looks for computer games. Thinking that he found a forthcoming game, he starts the program "Global Thermonuclear War" playing as the Soviet Union. It seems that this ends in a disaster, but then the protagonist suggests the computer to play Tic-Tac-Toe against itself. WOPR learns the concept of futility and concludes: "A strange game. The only winning move is not to play." Cycling through all the nuclear war scenarios it has devised, it finds that they to all result in stalemates: "WINNER: NONE" is the output on the screen and WORP cancels the launch of the second strike. In this movie the computer became a rational thinker, an artificial or at least a computational being that recompensed the fooling of human beings by making its own decision!

In 1979 and in 1984 two books appeared with almost equal titles: *Machines Who Think*, Pamela McCorduck's *Personal Inquiry Into the History and Prospects of Artificial Intelligence* [24] that is still a very good approach to the early history of AI[7], and *Machines That Think* [3], a compilation of 29 science fiction stories of the 20th century that originally have been published in the period of 1909–1973.[8] That collection (edited by Asimov et al.: [3]) comprises interesting examples of speculations of computers and robots in their respective future.

2 The Computer Era in Science Reality and Science Fiction

Traditional histories of computation, computers and Artificial Intelligence (AI) consider Alan Turing as the "father" of both computing and AI because he set up the mathematical basis for the theory of computation while still being a graduate student at Princeton University in 1936. He developed the concepts that now are considered as the basic elements of computation. His main contribution was to apply the idea of a "methodical process" (what people perform when pursuing any kind of organized action) to something that can be done "mechanically" by a machine. Though

[5] *WarGames*, 1983, American science fiction film; Director: John Badham; Co-writers: Lawrence Lasker and Walter F. Parkes.

[6] North American Aerospace Defense Command.

[7] The book appeared in 2004 in a new "25th anniversary edition" [25].

[8] The first story is Ambrose Pierce's *Moxon's Master* and the last is *Starcrossed*, written by George Zebrowski.

he didn't construct such a device, he mathematically demonstrated that this could be possible by proposing a hypothetical machine known since then as the "Turing machine". Turing gave for the first time the formal definition of what should count as a "definite method" (or, in modern language, simply "an algorithm"). That machine would be able to perform certain elementary operations by using a series of instructions, which have to be written in symbols of formal language (that is, in a *precise* form). His idea was that these symbols could be translated into a physical medium (which in Turing's example consisted on a paper tape). An "effective algorithm" was defined by Turing as a series of instructions that, applied to a set of data, allow us to achieve correct results. Turing's argument goes on by telling that, if each particular algorithm can be written out as a set of instructions in the same standard form, there could be a universal machine that can do what any other particular Turing machine would do. The "Universal Turing Machine" embodies the essential principle of the computer: a single machine for all possible tasks.

This abstract machine that represented the process of computing on a paper band subdivided into fields could solve every conceivable mathematical problem as long as there was an algorithm for it. In his paper "On Computable Numbers, with an Application to the Entscheidungsproblem" [46], Turing reformulated Kurt Gödel's (1906-1978) incompleteness-findings and he replaced Gödel's universal, arithmetic based, formal language with simple, formal "automata".

Turing's machine was a purely theoretical model, a kind of universal computer. However, this abstract idea of an automatic calculating machine was to be realized ten years later in the so-called era of computers that started in the 1940s. The first one was the electro-mechanical Z3 computer that was designed in 1941 by Konrad Zuse (1919–1995) in Berlin, Germany; the second was "the first electronic computer ABC" (Atanasoff-Berry-Computer) created by John V. Atanasoff (1903–1995) and Clifford E. Berry (1918–1963)[9]; the third were the digital and electronic "Colossus" computers in England designed by Tommy Flowers (1905–1998) with the help of Turing.[10] These were used to decrypt the Germans' Enigma codes during the Second World War in 1943. In 1944 we had the first large-scale electro-mechanical and digital computer, the Automatic Sequence Controlled Calculator (ASCC), later renamed Harvard Mark I, in 1947 Mark II, in 1949 the mostly-electronic Mark III and in 1952 the then all-electronic Mark IV. This series was conceptual designed by Howard Aiken (1900–1973), from 1944 to 1949 the mathematician Grace Murray Hopper (1906–1992) joined the project (for details see [36]).

Based on Turing's achievements, the idea of a "computing machine" changed in the late 1940s from the earlier conception of "computers" (or sometimes "computors") as women that performed computations, to apply that name to the machine that, based on digital equipment, was able to perform anything that could be described as "purely logical". Because of his demonstration that computation could be used for more than just mathematical calculations, the study of computability began to be a "science".

[9] However, the "ABC" was not general-purpose computer.

[10] "Colossus" was also a not general-purpose computer.

In 1945, almost one year before ENIAC was announced, the mathematician John von Neumann (1903–1957) was asked to prepare a report on the logical principles of its successor, the EDVAC (since the ENIAC had not had any such description and it had been sorely missed). The ENIAC had an electronic working memory, so the individual processing operations of the entered data were exceptionally fast. However, each program to be run had to be hard wired, and so reprogramming required several hours of work.

Von Neumann recognized very quickly, though, that this was a major drawback to the huge computer, and he was soon looking for ways to modify it. Today, the novel concept of a central programming unit in which programs are stored in a coded form is attributed to von Neumann. Instead of creating the program by means of the internal wiring of the machine, the program is installed directly in the machine. Basic operations like addition and subtraction remain permanently wired in the machine, but the order and combinations of these basic functions could be varied by means of instructions that were entered into the computer just like the data. The EDVAC was not supposed to suffer from the "childhood diseases" that had afflicted the ENIAC. To this end Neumann's principle of store programming was used and the principle that went down in the history of the computer as "Von Neumann architecture" was realized for the first time [31]. This "Von Neumann architecture" became also the basis of the first computer built under his direction by the Institute for Advanced Study (IAS) in Princeton, New Jersey.

In 1949, the year before *Eckert-Mauchly Computer Corporation* (EMCC) was sold to Remington Rand, Grace Hopper had become senior mathematician and joined the team developing the UNIVAC I and she developed the idea of machine-independent programming languages. Then, in March 1950, the UNIVAC computer (UNIVersal Automatic Computer) was delivered. This machine not only became known as the first commercial computer but also for predicting the outcome of the U.S. presidential election in the following year.

2.1 The "Absurdity of Computer Science Fiction"

"History is all about what already happened. So the historian and the science fiction writer might seem to be the two heads of Janus. One stares at the past, and tries to imagine how it might have been different and why it wasn't. The other stares at the future, and wonders how it will be." [14] Following the argument of the historian of computer technology, Thomas Haigh along with the American science fiction writer Kim S. Robinson, we can see here that "science fiction is 'an historical literature'." [14] Moreover, Robinson notes that in any work of science fiction "there is an explicit or implicit fictional history that connects the period depicted to our present moment or to some moment of our past" and Haigh concludes in Robinson's words that science fiction and historical fiction "are more alike, in some respects, than either is like the literary mainstream ... both are concerned with alien cultures, and with estrangement." ([14], p. 8, [35]) Haigh names it the “absurdity of science fiction as a literature of prediction, and its merit as a genre of historical writing” that “can be seen particularly clear in its treatment of computing. Computers show up in science fiction in the early 1950s, mirroring their arrival in the real world.” ([14], p. 9.)

The computing machines constructed in the first two decades of the computer era looked different from our 21st century imaginations of a computer, they acted different and they were different. As Clute wrote in 1995, “they were great, clumsy giants, and hardly more powerful than a wristwatch is today.” That book was published a long time ago and today’s wristwatches get ready to become or to merge with today’s computers. But the essence of Clute’s argument is true and he continued describing these machines of the 1940s and 1950s as follows: “The basic technology available still functioned, very crudely, through enormous and unreliable gadgets like vacuum tubes, programmed via hand-punched punch cards. It was a nightmare in the real world but it was not a nightmare in the world of SF.” ([10], p. 74)

The scientists who built the first computers used them for scientific calculation and in these first years, SF writers paid almost no attention to them. ([10], p. 74) “At first glance this is strange.” Clute wrote then, and he referred to the fact that many of the SF authors had a background or even a degree in a scientific or engineering discipline. For instance, Asimov[11] joined in 1951 the faculty of the Boston University School of Medicine but in 1958 he resigned from this position to become a full-time writer. Could SF writers with such a scientific background miss this technological revolution? — Clute plausibly surmises that “the computer appeared to present a challenge to *Homo sapiens*. The small amount of speculation about computers that appeared before the 1960s failed to see them as almost infinitely adaptable tools, concentrating instead on visions in which computers replaced humanity, or took over from humanity, or became God. The computer was not imagined simply because to do so was to welcome into our bosoms the ultimate enemy.” ([10], p. 75)

Haigh indicates that “Computers were unknown in Asimov’s best-known work of this era, the *Foundation Trilogy* (originally published from 1942 to 1950). Fifty thousand years from now scientists have achieved some miracles of miniaturization, including shrinking nuclear reactors to the size of walnuts for use in atomic-powered dishwashers and personal force fields. But they don’t seem to have invented computers. A separate stream of stories explored the three laws of robotics, depicting the development of ever more intelligent and human-like machines powered by the rather nebulous technology of “positronic brains”. Robots are common but computers remain very rare; a handful of “thinking machines” with “super robot brains” are used for economic control and scientific research. Asimov also wrote, from 1955 onward, a handful of stories concerned with a giant computer named Multivac, built with vacuum tubes and buried deep underground. This machine too fits the “giant brain” paradigm, and comes eventually to rule the world.” ([14], p. 10.)

[11] Asimov got a Bachelor in 1939 and a Master’s degree in 1941 from Columbia University in New York, and after the War in 1948 he returned to Columbia University to earn a Ph.D. in biochemistry.

Fig. 1 "Thinking Machine"; illustration in Eando Binder's story "The Cosmic Blinker", art by Frank R. Paul, 1953

2.2 Asimov's MULTIVAC

MULTIVAC is the name of a fictional supercomputer in some of Asimov's stories in the 1950s and — almost needless to say — it is an allusion to UNIVAC. Initially the name should mean "MULTIple VACuum tubes" but in 1956 in the story "The Last Question" Asimov translated the suffix AC to be "Analog Computer". In all the stories MULTIVAC is a computer that operates in ordinary to the government for security purposes. In the various stories MULTIVAC has different skills.

For one, in *Franchise* (1955) the future United States of the year 2008 use the system of a so-called "electronic democracy". A single person has been selected by the computer MULTIVAC to answer some questions. Then, MULTIVAC uses the answers and other data to predict the results of an election. Therefore, no actual election will be held.[12]

Other MULTIVAC-stories are: *Question* (1955); *Jokester* (1956); *The Last Question* (1956); *All the Troubles of the World* (1958); *The Machine that Won the War* (1961); *The Life and Times of MULTIVAC* (1975); *Point of View* (1975).

When Asimov published the story *Profession* in 1957, he told the reader of a society on the planet Earth in the 65th century. In that far future children are taught to read at the age of eight to eighteen and after that they will be educated by a process that is called "taping", i.e. a brain-computer interface. A computer analyzes the brain of every child and this analysis is the basis to determine their future profession at their "Education Day". The young humans have no chance to object or resist and the best educated of them have to compete in their profession in futuristic Olympic games. The winners in these "Olympics" have the chance of being "bought by an advanced Outworld if they are valuable for the colonies whereas to stay on Earth means to have an inferior status.

2.3 Zadeh's "Thinking Machines"

It seems that it originated from the early Computer Science and that it was Lotfi A. Zadeh who published the first science vision of a "Thinking Machine" in 1950 and he also predicted then that "Thinking Machines" may be commonplace anywhere from ten to twenty years hence and that they will play a major role in any armed conflict. Not until decades later new SF stories told these kinds of stories of computers that govern the world by their own decision — sometimes they annihilate the earth, sometimes they protect the planet.

In 1950, when Zadeh wrote "Thinking Machines: A New Field in Electrical Engineering" [49] (Figure 2), he was interested in "the principles and organization of machines which behave like a human brain, and as we said already, such machines were then variously referred to as "thinking machines", "electronic brains", "thinking robots", and similar names and with this article, he wanted first to clarify how a thinking machine differed from other machines. To do so, he used a very simple example:

> However, an idea of the principles involved in a thinking machine can be obtained from the description of a Tit-Tat-Toe playing device which was recently demonstrated by Robert Haufe at Caltech before a meeting of the American Institute of Electrical Engineers. ([49], p. 12)

In addition to chess, Tit-Tat-Toe, today better known as Tic-Tac-Toe, was one of the games that scientists wanted to teach machines to play early on. The game is played by two players on a board of three by three squares. The players take turns filling a square with their respective symbols (usually $\times$ and $\circ$). The game is won by the player who manages to place three of his symbols in a row (horizontally, vertically

[12] Contingently the correct predicting of the U.S. presidential election's outcome in the year 1952 motivated Asivmov to write this story.

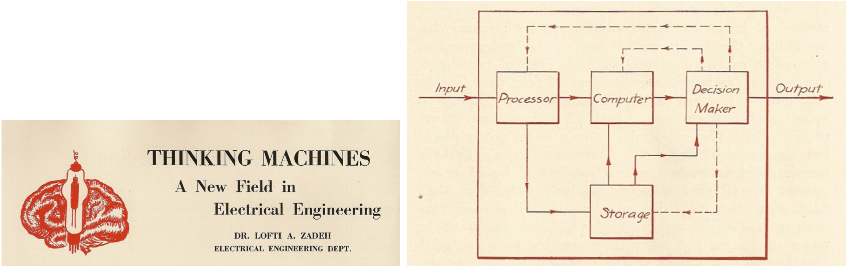

Fig. 2 Left: Illustration accompanying Zadeh's article [49], the author's first name was misspelled here. Right: Zadeh's chart for the basic elements of a "Thinking Machine"

or diagonally). Haufe's machine functioned with relay circuits. It saved information about which of the individual fields were filled with the players' symbols, it could make sensible moves and could indicate the result at the end of the game. When it was the machine's turn, it classified all nine fields according to whether or not filling them was strategically desirable. These classes were then searched for empty fields. An empty field with the highest strategic value was then filled. ([15], p. 885.)

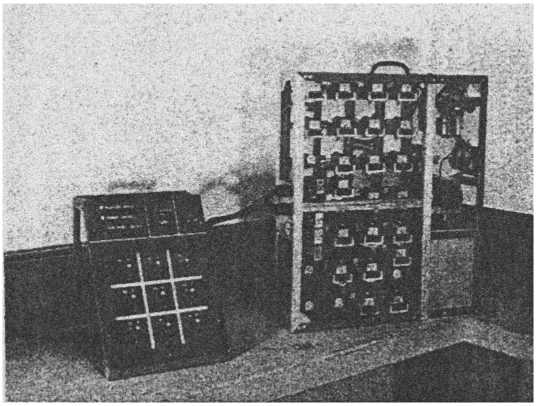

Fig. 3 The two units comprising Robert Haufe's Tit-Tat-Toe machine

Haufe's Tic-Tac-Toe machine, which Zadeh displayed in his article (Figure 3), was naturally much simpler than other machines that were referred to as "thinking machines". However, Zadeh considered the ability to make decisions to be a characteristic feature of thinking machines:

> Despite its simplicity, Haufe's machine is typical in that is possesses a means for arriving at a logical decision based on evaluation of a number of alternatives. More generally, it can be said that a thinking machine is a device which arrives at a certain decision or answer through a process of evaluation and selection. ([49], p. 13)

Zadeh's diagram (Fig. 2) demonstrates the "thinking" process of such machines: Incoming input data are sorted and processed in the processor. Some of this processed data is then sent to storage to be saved for later use (this storage can be in the form of punch cards, tapes or cathode ray tubes), "and it has the same function as memory in a human brain". ([49], p. 13)

Another portion of the processed data as well as some of the saved data are called up into the unit known as the computer where necessary calculations are performed. The computer is not the essential component of the thinking machine, however, unless the calculation either is the end result itself or will be needed at the end in order to make the decision. More important is the *decision maker*, for it is here that decisions are reached. All of the relevant information coming from the computer and from storage is evaluated and weighted according to the commands and criteria present within the machine. The final answer or decision is formed on this basis as output. Dashed lines lead from the decision maker to all three elements of the machine: These are the so-called feedback connections. This feedback allows the three elements to operate as a function of the data obtained from the decision maker as needed.

In a footnote Zadeh mentioned that the "same names are frequently ascribed to devices which are not 'thinking machines' in the sense used in this article", therefore he separated them as follows: "The distinguishing characteristic of thinking machines is the ability to make logical decisions and to follow these, if necessary, by executive action." ([49], p. 12.)

He stated: "More generally, it can be said, that a thinking machine is a device which arrives at a certain decision or answer through the process of evaluation and selection." With this definition he decided: "Thus, M.I.T.'s differential analyser is not a thinking machine, for it can not make any decisions, except trivial ones, on its own initiative. However, the recently built large-scale digital computers, UNIVAC and BINAC[13], are endowed with the ability to make certain non-trivial decisions and hence can be classified as thinking machines." ([49], p. 13.) Zadeh explained in this article "how a thinking machine works" and he claimed that "the box labeled Decision Maker is the most important part of the thinking machine".

2.4 Zadeh's "Electronic Admission Director"

Zadeh found a very interesting exemplification of his imagination of a "Thinking Machine" in 1950 and this picture resembles the concept of Asimov's computer in *Profession*. He illustrated his argumentation by peering forward into the year 1965. Three years earlier, in this version of the future, the administration at Columbia University had decided, for reasons of economy and efficiency, to close the admissions office and install in its place a thinking machine called the "Electronic Admissions Director". The construction and design of this machine had been entrusted to the electrical engineering department, which completed the installation in 1964.

[13] The Binary Automatic Computer was the first stored-program computer in the US, built at EMCC in 1949.

Since then, the "director" has been functioning perfectly and enjoying the unqualified support of the administration, departments and students. This thinking machine functions as follows:

1. Human secretaries convert the information from the list of applicants into series of numbers $a_1, a_2, a_3, \ldots, a_n$; each number represents a characteristic, e.g. a_1 could stand for the applicant's IQ, a_2 for personal character, and so on.
2. The lists coded thusly are provided to the *processor*, which processes them and then relays some of the data to the *computer* and another part of the data to *storage*. On the basis of applicant data as well as university data, the *computer* calculates the probabilities of various events, such as the probability that a student will fail after the first five years. This information and the saved data are sent to the *decision maker* to come to final decision on whether to accept the applicant. The decision is then made based on directives, such as these two:
   - accept if the probability of earning the Bachelor's degree is greater than 60%;
   - reject if the probability that the applicant will not pass the first year of college is greater than 20%.

Zadeh didn't consider the machine sketched out here to be as fanciful as student readers (and surely others, as well) may have thought: Machines such as this could be commonplace in 10 or 20 years and it is already absolutely certain that thinking machines will play an important role in armed conflicts that may arise in the future. ([49], p. 30) Back then, in the year 1950, though, there was still much to be done so that these or similar scenarios of the future could become reality.

3 Making Computers Think (Like People?)

In 1948 the young mathematician John McCarthy (1927–2011) had attended the "Hixon Symposium on Cerebral Mechanisms in Behaviour" at Caltech where he became acquainted with Warren S. McCulloch (1898–1969) who gave his famous talk on "Why the Mind Is in the Head" [39], and other well-known members of the so-called "Cybernetics group" [16]. During that symposium he also met the mathematicians Turing and von Neumann, the psychologist Karl S. Lashley (1890–1958) and Claude Shannon. This event initiated his life-time interests related to the development of "machines that could think". In the following year he changed to Princeton to study automata models with von Neumann and he became friends with his fellow student Marvin L. Minsky (born in 1927). In 1951 he received his Ph.D. graduation at Princeton University, he spent the following year at Bell Labs and he eventually discussed the idea of machine intelligence with Shannon. He argued him into collecting and publishing scientific works on machines that seem to be intelligent. The two edited the well-regarded and influential collection *Automata Studies* that got this technical title because Shannon did not like provoking headings. The voluminous tome appeared in print in 1956 [45] and here Automata theory and Turing machines were treated from different sides. But McCarthy was dissatisfied with the content of these papers concerning the potential of creating "intelligent computers"! In the mid-1950s he wished "to nail the flag to the mast," he said at the AI@50-conference in 2006 [21].

3.1 Artificial Intelligence

In 1955 McCarthy got an assistant professorship of mathematics at Dartmouth College in Hanover, New Hampshire. Here he initiated AI when he started to organize a "Summer Research Project on Artificial Intelligence" modeled on the traditional military summer schools. In the proposal to this project McCarthy wrote that AI-research will "proceed on the basis of the conjecture that every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it" [23]. Even this provoking text and moreover the provoking name "Artificial Intelligence" in the heading that were McCarthy's conceptions, the proposal appeared officially under the authorship of McCarthy, Minsky, the prominent IBM computer designer Nathaniel Rochester (1919–2001) and the well-known Shannon who was in that year going to join MIT.

The Dartmouth workshop was held during one month in the summer of 1956 and ten people took part, among the organizers McCarthy, Minsky, Rochester and Shannon, there were Raymond J. Solomonoff (1926-2009), Oliver G. Selfridge (1926-2008), Trenchard More, Arthur L. Samuel (1901-1990), Herbert A. Simon (1916-2001) and Allan Newell (1927-1992). It was a meeting of brainstorming discussions on the potential of information technology between experts in language, sensory input, learning machines and other fields; it helped focusing AI research for the future. McCarthy recalled later that he was "disappointed in how few research papers dealt with making machines behave intelligently. [...] But the real reason we didn't live up to grand hopes was that AI was harder than we thought." [21] James Moor wrote what McCarthy also emphasized basically when he spoke at the AI@50-meeting: "Nevertheless there were important research developments at the time, particularly Allen Newell's, John C. Shaw's (1922–1991), and Herbert Simon's Information Processing Language (IPL) and the Logic Theory Machine" ([29], p. 87). The system of this Carnegie Mellon-researcher trio was proving elementary logical theorems and playing games. Symbols for objects like chess figures or truth values had to be manipulated by the used program language and to this end the three established the concept of "list structures" that enthused the other participants. Minsky tried to build a geometry problem solver as an application of the rule-based approach that was proposed by Newell and Simon and Rochester and Herbert Gelernter started the trial to implement the program. Moor summed up that the Dartmouth project "was not really a conference in the usual sense. There was no agreement on a general theory of the field and in particular on a general theory of learning. The field of AI was launched not by agreement on methodology or choice of problems of general theory, but by the shared vision that computers can be made to perform intelligent tasks" ([29] p. 87).

The subsequent history of AI research is a story of several successes but has yet lagged behind expectations. AI became a field of research to build computers and computer programs that act "intelligently" although no human being controls those systems. AI methods became methods to compute with numbers and find exact solutions. However, not all problems can be resolved with these methods. On the other hand, humans are able to resolve such tasks very well, as Zadeh mentioned in many speeches and articles over the last decades. In conclusion, he stated that "thinking machines" do not think as humans do. From the mid-1980s he focused on "Making Computers Think like People" [52]. For this purpose, the machine's ability "to compute with numbers" should be supplemented by an additional ability that is similar to human thinking: Computing with Words and Perceptions. To this end a new mathematical theory was necessary.

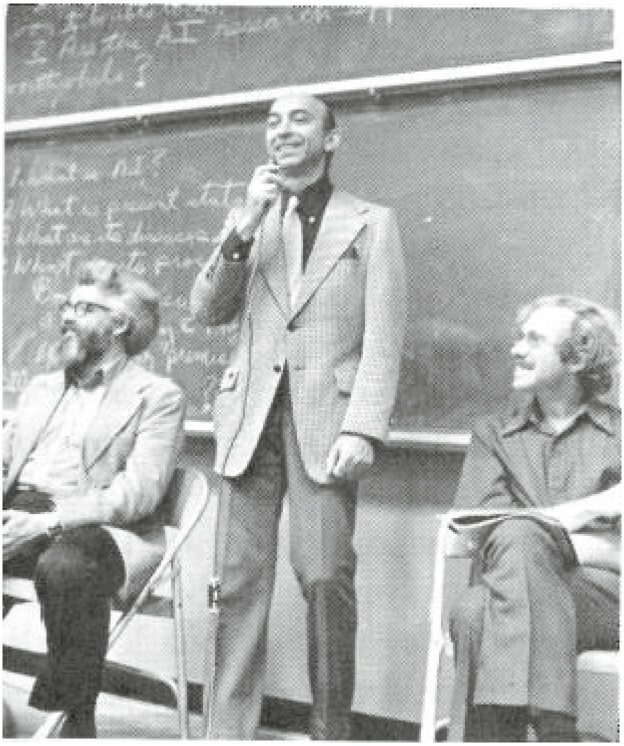

Fig. 4 Zadeh moderating an annual AI debate at Berkeley; from left to right: John McCarthy, Lotfi A. Zadeh, Hubert Dreyfus (University of California, Berkeley)

3.2 Fuzzy Sets and Systems

In 1959 Zadeh became professor at the University of California at Berkeley and in the course of writing the book *Linear System Theory: The State Space Approach* [56] with his colleague Charles A. Desoer (1926–2010), he "began to feel that complex systems cannot be dealt with effectively by the use of conventional approaches largely because the description languages based on classical mathematics are not sufficiently expressive to serve as a means of characterization of input-output relations in an environment of imprecision, uncertainty and incompleteness of information." [41] There were two ways to overcome this situation. In order to describe the actual systems appropriately, he could try to increase the mathematical precision even further, but Zadeh failed with this course of action. The other way presented itself to Zadeh in the year 1964, when he discovered how he could describe real systems as they appeared to people. "I'm always sort of gravitated toward something that would be closer to the real world" [42].

In order to provide a mathematically exact expression of experimental research with real systems, it was necessary to employ meticulous case differentiations, differentiated terminology and definitions that were adapted to the actual circumstances, things for which the language normally used in mathematics could not account. The circumstances observed in reality could no longer simply be described using the available mathematical means.

While he was serving as Chair of the department in 1963/64, he continued to do a lot of thinking about basic issues in systems analysis, especially the issue of unsharpness of class boundaries. These thoughts indicate the beginning of the genesis of Fuzzy Set Theory." ([55], p. 7).

In his first article "Fuzzy Sets" he launched new mathematical entities as classes or sets that "are not classes or sets in the usual sense of these terms, since they do not dichotomize all objects into those that belong to the class and those that do not." He introduced "the concept of a fuzzy set, that is a class in which there may be a continuous infinity of grades of membership, with the grade of membership of an object x in a fuzzy set A represented by a number $f_A(x)$ in the interval $[0,1]$." [50][14]

Since that time he often compared the strategies of problem solving by computers on the one hand and by humans on the other hand. In a conference paper in 1970 he called it a paradox that the human brain is always solving problems by manipulating "fuzzy concepts" and "multidimensional fuzzy sensory inputs" whereas "the computing power of the most powerful, the most sophisticated digital computer in existence" is not able to do this. Therefore, he stated that "in many instances, the solution to a problem need not be exact", so that a considerable measure of fuzziness in its formulation and results may be tolerable. The human brain is designed to take advantage of this tolerance for imprecision whereas a digital computer, with its need for precise data and instructions, is not." ([51], p. 132) He continued: "Although present-day computers are not designed to accept fuzzy data or execute fuzzy instructions, they can be programmed to do so indirectly by treating a fuzzy set as a data-type which can be encoded as an array [...]." Granted that this is not a fully satisfactory approach to the endowment of a computer with an ability to manipulate fuzzy concepts, it is at least a step in the direction of enhancing the ability of machines to emulate human thought processes. It is quite possible, however, that truly significant advances in artificial intelligence will have to await the

[14] For more details on the genesis of the theory of Fuzzy Sets and Systems see: [43], chapter V.

development of machines that can reason in fuzzy and non-quantitative terms in much the same manner as a human being." ([51], p. 132)

3.3 Artificial Neural Networks

In 1943 Warren McCulloch and the 19-year-old math student Walter H. Pitts (1923–1969) published "A Logical Calculus of the Ideas Immanent in Nervous Activity" [26]. The text linked the activities of a network of abstract electric on-off switches, so-called neurons, with a complete logical calculus for time-dependent signals in electric circuits with synaptic delays. By modeling these neurons after electric on-off switches, which can be interconnected such that each Boolean statement can be realized, McCulloch and Pitts now "realized" the entire logical calculus of propositions by "neuron nets".

Every McCulloch-Pitts neuron is a threshold element: If the threshold value is exceeded, the neuron becomes active and "fires". By "firing" or "not firing", each neuron represents the logical truth values "true" or "false". Appropriately linked neurons thus carry out the logical operations like conjunction, disjunction, etc.

Two years later von Neumann picked the paper up and used it in teaching the theory of computing machines [31] and may be that initiated the research program of "Neuronal Information Processing", a collaboration involving psychology and sensory physiology, in which other groups of researchers were soon interested. Some years later, von Neumann wrote on his comparative view on the computer and the brain in an unfinished manuscript that was published posthumously after he died because of cancer.[30]

In 1951, Minsky had worked with Dean Edmonds in Princeton to develop a first neurocomputer, which consisted of 3,000 tubes and 40 artificial "neurons" was called SNARC (Stochastic Neural-Analog Reinforcement Computer), in which the weights of neuronal connections could be varied automatically. But SNARC was never practically employed.

The classic problem that a computer at that time was supposed to solve, and hence an artificial neuronal network was expected to, was the classification of patterns of features, such as handwritten characters. Under the concept of a pattern, objects of reality are usually represented by pixels; frequency patterns that represent a linguistic sign, a sound, can also be characterized as patterns. In 1957/1958, Frank Rosenblatt (1928–1971) and Charles Wightman at Cornell University developed a first machine for pattern classification. Rosenblatt described this early artificial neuronal network, called Mark I Perceptron, in an essay for the *Psychological Review* [37]. It was the first model of a neuronal network which was capable of learning and in which it could be shown that the proposed learning algorithm was always successful when the problem had a solution at all.

The perceptron appeared to be a universal machine and Rosenblatt had also heralded it as such in his 1961 book *Principles of Neurodynamics: Perceptrons and the Theory of Mind*:

> "For the first time, we have a machine which is capable of having original ideas. ... As concept, it would seem that the perceptron has established, beyond doubt, the feasibility and principle of nonhuman systems which may embody human cognitive functions ... The future of information processing devices which operate on statistical, rather than logical, principles seems to be clearly indicated." [37]

The euphoria came to an abrupt halt in 1969, however, when Minsky and Seymour Papert (born 1928) completed their study of perceptron networks and published their findings in a book. [27] The results of the mathematical analysis to which they had subjected Rosenblatt's perceptron were devastating: Artificial neuronal networks like those in Rosenblatt's perceptron are not able to overcome many different problems! For example, it could not discern whether the pattern presented to it represented a single object or a number of intertwined but unrelated objects. The perceptron could not even determine whether the number of pattern components was odd or even. Yet should this have been a simple classification task that was known as a "parity problem". The either-or operator of propositional logic, the so-called XOR, presents a special case of the parity problem that thus cannot be solved by Rosenblatt's perceptron. Therefore, the logical calculus realized by this type of neuronal networks was incomplete. As a result of this fundamental criticism, many projects on perceptron networks or similar systems all over the world were shelved or at least modified. It took many years for a revival of this branch of AI research.

Since 1981 the psychologists James L. McClelland (born in 1948) and David E. Rumelhart (1942–2011) applied Artificial Neural Networks to explain cognitive phenomena (spoken and visual word recognition). In 1986, this research group published the two volumes of the book *Parallel Distributed Processing: Explorations in the Microstructure of Cognition* [38]. Already in 1982 John J. Hopfield, a biologist and Professor of Physics at Princeton, CalTech, published the paper "Neural networks and physical systems with emergent collective computational abilities" [18] on his invention of an associative neural network (now more commonly known as the "Hopfield Network"), i.e.: Feedback Networks that have only one layer that is both input as well as output layer and each of the binary McCulloch-Pitts Neurons is linked with every other, except itself.

McClelland's research group could show that perceptrons with more than one layer can realize the logical calculus; multi layer perceptrons were the beginning of the new direction in AI: Parallel Distributed Processing.

3.4 Evolutionary Strategies

In 1940 the immigrated mathematician Stanislaw Ulam (1909–1984) had studied the growth of crystals at Los Alamos National Laboratory. When looking for a model of discrete dynamic systems he had the idea of a cellular automaton and he created a simple lattice network. The states of Ulam's cells at a certain point in time t were determined by its state at point in time instantaneous before t. Von Neumann picked up this idea in 1953 when he conceptualized a theory of self-reproducing two-dimensional cellular automata with a self-replicator implemented algorithmic.

There was a universal copier and constructor working within a cellular automaton with 29 states per cell and von Neumann could show that a particular pattern would copy itself again and again within the given pool of cells.

Following up this concept von Neumann was wondering if self-reproducing of automata also could pursue an evolutionary strategy, i. e. due to mutations and struggle for resources. Unfortunately there is no paper by von Neumann on this subject. Arthur W. Burks (1915–2008), a mathematician and philosopher who was von Neumann's collaborator in the IAS computer project since 1946, expanded the theory of automata, completed and edited the paper "Theory of Self-Reproducing Automata", von Neumann had been working on, posthumously. The paper was published in 1966 and it "had a huge impact, not only in computing but in biology and philosophy as well," said John H. Holland (born 1929), professor of psychology, electrical engineering and computer science at the University of Michigan in Ann Arbor. "Until then, it was assumed that only living things could reproduce." [19] and shortly after this field of research was named "Evolutionary Computing". Holland was a member of Burk's "Logic of Computers Group", in 1954 he was among the first students in the new Ph.D. program "Computer and Communication science" and the first to graduate in 1959.

Holland was affected by the book *The Genetical Theory of Natural Selection*, written by English statistician and evolutionary biologist Sir Ronald A. Fisher (1890–1962), and he was warm on analogies of evolutionary theory and animal breeding from a computer science point of view: Can we breed computer programs? "That's where genetic algorithms came from. I began to wonder if you could breed programs the way people would say, breed good horses and breed good corn", Holland recalled later ([28], p. 128). In his *Adaptation in Natural and Artificial Systems*, that he published in 1975, he showed how to use these "genetic" search algorithms to solve real-world problems. His research objectives were i) the theoretical explanation of adaptive processes in nature and ii) the development of software that keeps the "mechanisms" of natural systems and adapting to the respective circumstances at the best. [17]

The name "Genetic Algorithms" goes back to the Ph.D. thesis of John D. Bagleys under Holland's supervision [4]. Bagley applied these algorithms to find solutions in game theoretic problems and more of Holland's Ph. D students, e.g. Kenneth De Jong and David E. Goldberg, could demonstrate other successful applications.

Almost at the same time so-called "Evolutionary Programming" appeared with the research work of Lawrence G. Fogel (1928–2007) from the University of California, Los Angeles [13]. In 1966 the book *Artificial Intelligence through Simulated Evolution* appeared, co-authored by Fogel, Al Owens und Jack Walsh. These biological inspired research programs merged to the now so-called field of "Evolutionary Computation."

Apart from these developments in the US other natural inspired principles have been considered in Germany: In the 1960s, Ingo Rechenberg (born 1934) and Hans-Paul Schwefel (born 1940), two students of aircraft construction at the Technical University of Berlin, suggested to consider the theory of biological evolution to develop optimization strategies in engineering. In 1963 they founded the "inofficial working group Evolutionstechnik" performing "experimental optimization" of the shape of wings and kinked plates through mostly small modifications of the variables via a random manner. This was the seminal idea of the research field "Evolution Strategies", which was initially handled without computers. However, some time later, Schwefel expanded the idea toward evolution strategies to deal with numerical/parametric optimization and, also, formalized it as it is known nowadays. [34], [40].

4 Soft Computing

"The concept of soft computing crystallized in my mind during the waning months of 1990" wrote Lotfi Zadeh in 2001 [53]. He coined this label 'Soft Computing' (SC) to name an interdisciplinary field that covers different approaches to Artificial Intelligence that had been developed during the last decades but weren't part of the mainstream of AI: He formulated this new scientific concept when he wrote that

> "what might be referred to as soft computing — and, in particular, fuzzy logic — to mimic the ability of the human mind to effectively employ modes of reasoning that are approximate rather than exact. In traditional — hard — computing, the prime desiderata are precision, certainty, and rigor. By contrast, the point of departure in soft computing is the thesis that precision and certainty carry a cost and that computation, reasoning, and decision making should exploit — wherever possible — the tolerance for imprecision and uncertainty. [...] Somewhat later, neural network techniques combined with fuzzy logic began to be employed in a wide variety of consumer products, endowing such products with the capability to adapt and learn from experience. [...] Underlying this evolution was an acceleration in the employment of soft computing — and especially fuzzy logic — in the conception and design of intelligent systems that can exploit the tolerance for imprecision and uncertainty, learn from experience, and adapt to changes in the operation conditions." [52]

Zadeh defined a new approach and also a "new direction in AI" [54], because he is committed to the assumption that traditional AI couldn't cope with the future challenges. He directed his critique to the general approach of Computer Science and Engineering, which he calls "hard computing".

In the foreword to the new journal *Applied Soft Computing* he recommended that instead of "an element of competition" between the complementary methodologies of SC "the coalition that has to be formed has to be much wider: it has to bridge the gap between the different communities in various fields of science and technology and it has to bridge the gap between science and humanities and social sciences! SC is a suitable candidate to meet these demands because it opens the fields to the humanities. [...] Initially, acceptance of the concept of soft computing was slow in coming. Within the past few years, however, soft computing began to grow rapidly in visibility and importance, especially in the realm of applications which are related to the conception, design and utilization of information/intelligent systems. This is the backdrop against which the publication of *Applied Soft Computing* should be viewed. By design, soft computing is pluralistic in nature in the sense that it is a coalition of methodologies which are drawn together by a quest for accommodation with the pervasive imprecision of the real world. At this juncture, the principal members of the coalition are fuzzy logic, neuro-computing, evolutionary computing, probabilistic computing, chaotic computing and machine learning." ([53], p. 1–2)

In 2010 Luis Magdalena, General Director of the *European Centre for Soft Computing* in Mieres, Asturias (Spain), that was founded in 2006, accompanied Zadeh in distinguishing between "Soft Computing as opposite to Hard Computing" (HC) saying that the "conventional approaches" of HC "gain a precision that in many applications is not really needed or, at least, can be relaxed without a significant effect on the solution" and that the "more economical, less complex and more feasible solutions" of SC are sufficient. He pointed out that using sub-optimal solutions "that are enough" is "softening the goal of optimization" to be satisfied with inferring "an implicit model from the problem specification and the available data." Inversely we can say that without an explicit model we will never find the optimal solution. But this is not a handicap! — SC makes a virtue out of necessity because it is a "combination of emerging problem-solving technologies" for real-world problems and this means that we have only "empirical prior knowledge and input-output data representing instances of the system's behavior."[20]

Also computer scientist Piero Bonissone stated, in these cases of "ill-defined systems", that are "difficult to model and with large-scale solution spaces" "precise models are impractical, too expensive, or non-existent. [...] Therefore, we need approximate reasoning systems capable of handling such imperfect information. Soft Computing technologies provide us with a set of flexible computing tools to perform these approximate reasoning and search tasks." [8]

When Hans-Jürgen Zimmermann, founding editor of the journal *Fuzzy Sets and Systems*, foresaw that the development of "hybrid systems" of "fuzzy-neuro-evo-combinations" would continue in the future, he deliberated about a name for the common field of research, which would then also become the subtitle of the journal. "Soft computing, biological computing and computational intelligence have been suggested so far." These concepts seemed to be attractive in different ways and also varied with respect to their expressive power. He suggested calling the field "soft computing and intelligence" since the other concepts seemed to place too much emphasis on "computing" "which is certainly not appropriate at least for certain areas of fuzzy set theory." [57]. Thus since the first issue of 1995 *Fuzzy Sets and Systems* has appeared with the subtitle *International Journal for Soft Computing and Intelligence*.

5 Computational Intelligence

The name "Computational Intelligence" (CI) originates from a Canadian journal on the topic of AI.[15] When this journal was founded in 1985, the editorial board chose this name "to reflect the fact that AI is distinct from other studies of intelligence in its emphasis on computational models," the editors recalled about 10 years later and

[15] http://eu.wiley.com/WileyCDA/WileyTitle/productCd-COIN.html

Fig. 5 In the year 2006 the *European Centre for Soft Computing* was launched. First row (among others: Lotfi A. Zadeh, and Enric Trillas; back row (among others): Rudolf Kruse, Luis Magdalena, Henri Prade, Janusz Kacprzyk.

they continued: "The name was also short enough to be catchy but general enough to reflect our purpose and attract submissions from all areas of AI." [9].

In "CI" the adjective "computational" was intended to refer to subsymbolic problem representation, knowledge aggregation and information processing. Here, we reach the basics of natural intelligence but — as a matter of course — it is important to distinguish between natural (biological) intelligence and AI.

As computer scientist Włodzisław Duch wrote in 2004, CI "is used as a name to cover many existing branches of science. This name is used sometimes to replace artificial intelligence, both by book authors and some journals." [11][16]

As Zadeh did when he launched SC, Duch directed his critique to Symbolic AI: He surmises that "the idea that all intelligence comes from symbol manipulation has been perhaps misunderstood by the AI community". He stressed that psychologists Newell, Simon and Shaw[17] of the Carnegie-Rand group[18] dealt with formal symbol manipulations when they presented the *Logical Theory Machine*, that could proof

16 Duch referred to [33] and the above mentioned journal.

17 They were the so-called "NSS-group", "NSS" was the name of a chess program, the initials of its authors.

18 Carnegie-Mellon University and Rand-Corporation.

mathematical theorems in elementary logic,[19] and also three years later when they presented the *General Problem Solver* [32].

Duch pointed that these AI pioneers "wrote about physical symbols, not about symbolic variables. Physical symbols are better represented as multi-dimensional patterns representing states of various brain areas. Symbolic models of brain processes certainly do not offer accurate approximations for vision, control or any other problem that is described by continuous rather then symbolic variables. Approximations to brain processes should be done at a proper level to obtain similar functions. Symbolic dynamics [...] and extraction of finite state automata from recurrent networks [...] may provide useful information on dynamical systems, and may be useful in modelling transition between low-to-high-level processes."[12]

Moreover, in 2007 Duch noticed that the problems that "are at present solved in a best way by the AI community using methods based on search, symbolic knowledge representation, reasoning with frame-based expert systems, machine learning in symbolic domains, logics and linguistic methods", are "non-algorithmizable problems involving systematic thinking, reasoning, complex representation of knowledge, episodic memory, planning, understanding of symbolic knowledge". [12]

In early years CI was a collection of methods but now there exist attempts to characterize this research area explicitly as defined: "CI studies problems for which there are no effective algorithms, either because it is not possible to formulate them or because they are NP-hard and thus not effective in real life applications!" [12] As opposed to artificial systems, animate systems like living brains are able to solve problems for which there are no effective algorithms: "extracting meaning from perception, understanding language, solving ill-defined computational vision problems thanks to evolutionary adaption of the brain to the environment, survival in a hostile environment." [12] Accordingly: "A good part of CI research is concerned with low-level cognitive functions: perception, object recognition, signal analysis, discovery of structures in data, simple associations and control. Methods developed for this type of problems include supervised and unsupervised learning by adaptive systems, and they encompass not only neural, fuzzy and evolutionary approaches but also probabilistic and statistical approaches, such as Bayesian networks or kernel methods." Duch also recollects that "These methods are used to solve the same type of problems in various fields such as pattern recognition, signal processing, classification and regression, data mining."[12]

Also Magdalena, expressed "the idea of CI being the branch of science considering those problems for which there is not an exact model, plus those cases where the model exists but its consideration is not computationally effective, i.e., when we need to reduce the granularity or soften the goal." He also brought out that these ideas describe also "SC as the opposite to hard computing or based on its essential properties. So, apparently there is no significant difference between Soft Computing and Computational Intelligence." [20]

However, there is "little overlap between problems solved using low and high-level mental functions, although they belong to the same broader category of

[19] They showed it on the 1956 founding AI workshop in Dartmouth.

non-algorithmizable problems," Duch said and therefore he accentuates distinctly: "AI is a part of CI focusing on problems that require higher cognition and at present are easier to solve using symbolic knowledge representation. It is possible that other CI methods will also find applications to these problems in future. The main overlap areas between low and high-level cognitive functions are in sequence learning, reinforcement and associative learning, and distributed multi-agent systems. All tasks that require reasoning based on perceptions, such as robotics, automatic car driving, autonomous systems, require methods for solving both low and high-level cognitive problems and thus are a natural meeting ground for AI experts with the rest of the CI community."[12]

Another view on CI arrives at a different relationship of AI and CI; this view emerged from James Bezdek's reflections "On the Relationship between Neural Networks, Pattern Recognition and Intelligence" in 1992 [6] that let him to the first definition of CI. Bezdek considered three levels of system complexity that he named the "ABCs of neural networks, pattern recognition, and intelligence." The ABCs if interest to us are the following:

" A Artificial	Nonbiological (manmade)
B Biological	Physical + chemical + (??) = organic
C Computational	Mathematics + manmade machines"

Bezdek illustrated his view of the relationships between these ABCs and neural nets (NN), pattern recognition (PR), and intelligence (I) in Fig. 6. Here "complexity increases from left to right and from bottom to top" and: "Familiar terms in Fig. 6 include ANN, AI, and the three biological notions in the first row."[20]

He discussed Fig. 6 starting at the uppermost row: "The BNN is one of the physiological systems that facilitates organisms (in particular, humans) to perform various biological recognition tasks. One key input to the BNN is sensory data; another 'knowledge.' In turn BPR is but one aspect of biological intelligence. Some writers refer to the BNN as the hardware of the human body, the brain; BI then corresponds to the software of the human body, the mind. At the other end of the complexity spectrum, and I believe, in an entirely analogous way, computational NNs that depend solely on sensor data are (but one!) facilitator of computational PR, which in turn is but one aspect of computational intelligence. The middle row (A = Artificial) is perhaps the most interesting, for it offers us a means of extending low-level computational algorithms upwards toward their biological inspirations." Considering "other differences . . . between the B, A, and C levels of complexity", he emphasized that "(strictly) computational systems" depend on numerical data supplied by manufactured sensors and do not rely upon 'knowledge'." ([6], p. 88).

Then, Bezdek emphasized that "it is especially important and useful, in the context of the relationship between NNs and PR, to distinguish more carefully than usual what is meant by the term knowledge. Also the word 'artificial' raised trouble, when Bezdek wrote his paper: it seemed "much more properly applied in its usual context in AI than as it is currently used in NNs. Currently, it seems that the

[20] Note: BNN stands for *Biological* Neural Networks, BPR stands for *Biological* Pattern Recognition, and BI stands for *Biological* Intelligence, etc.

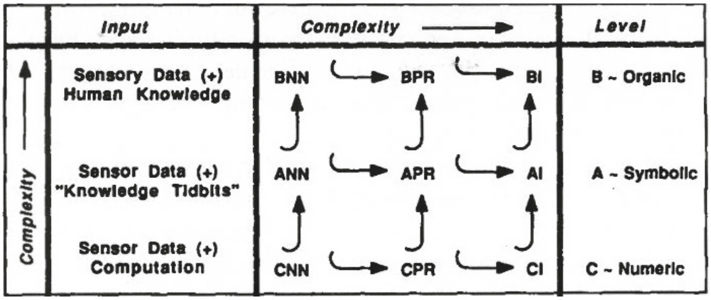

Fig. 6 Bezdek's "ABCs: Neural networks, pattern recognition, and intelligence", [6]

ANN is 'artificial' if it is not biological, that is, ANN is the complement of the BNN in the usual set-theoretic sense. However, I suggest a finer distinction between CNN and ANN, one that is connected to the term 'knowledge tidbits' in Figure 6." ([6], p. 88)

It was this sentence that was later used as a definition for CI in the introduction to the 1994 published book *Computational Intelligence: Imitating Life*, where the editors continued: "Artificial intelligence, on the other hand, uses what Bezdek calls 'knowledge tidbits'. Many NN's called 'artificial' should, Bezdek argues, be called computational NN's." ([59], p. v.)

In his contribution to the same book Bezdek responded to Fig. 6 more explicite: "The symbol ($\hookrightarrow$) in this figure means 'is a proper subset of'. For example, I am suggesting along the bottom row that CNNs $\subset$ CPR $\subset$ CI, and in the left column, that CNNs $\subset$ ANNs $\subset$ BNNs. As defined then, any computational system is artificial, but not conversely. So, I am definitiely suggesting that CI and AI are not synonyms. CI is in my view a proper subset of AI." In this paper Bezdek defined "CI systems" as follows:

> "A system is computationally intelligent when it: deals with only numerical (low-level) data, has pattern recognition components, does not use knowledge in the AI sense; and additionally when it (begins to) exhibit 1) computational adaptivity, 2) computational fault tolerance, 3) speed approaching humanlike turnaround and 4) error rates that approximate human performance." [7]

6 Conclusion

Concluding this chapter I would like to come back once again to Jim Bezdek's scheme in Fig. 6 that shows complexity levels in two dimensions: in Bezdek's words: "I think that A, B, and C correspond to three different levels of system complexity, which increase from left to right, and from bottom to top in this sketch." [7] When scientists try to create intelligent systems it means that this systems should perform (approximately) like *biological intelligent* (BI) systems. The way to reach this goal leads up and to the right by increasing complexity in both dimensions.

Bezdek pointed out that the concept "CI" is, however, only seductive as long as the concept of intelligence is no better defined than it currently is [7]. That means that in future times perhaps a similar scheme of complexity but showing more than two dimensions will be appropriate and paths to create an intelligent system — a "Thinking Machine" go labyrinthine ways to increase complexity. Science visions and science fictions will always try to show how such paths could appear but they will still base on their historical level of knowledge (tidbits)!

In December 1967, Isaac Asimov wrote a short text entitled "The Thinking Machine". The first sentence of this paper is: "The difference between a brain and a computer can be expressed in a single word: complexity." He argued that computers are programmed to solve problems and also human beings are programmed. Computers can only do what they are programmed to do; the same is true for humans, he wrote: "Our genes 'program' us the instant the fertilized ovum is formed, and our potentialities are limited by that 'program'." However, our program is that much more complex than computers have been in that time and still they are, but Asimov assumed that "if a computer can be made complex enough, [...] as complex as a human brain, it could be the equivalent of a human brain and do whatever a human brain can do." Moreover, his science vision — or is it science fiction? — says further that "we will perhaps build a computer that is at least complex enough to design another computer more complex than itself. This more complex computer could design one still more complex and so on and so on." [2] In this scenario it happens that computers "not only duplicate the human brain — but far surpass it." Then, there are two possibilies: "we ought to step aside" or the computers "push us aside".

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